

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 23 March 2000		2. REPORT TYPE Conference Proceedings		3. DATES COVERED (From - To) 5-9 September, 2000	
4. TITLE AND SUBTITLE Acoustic Propagation in Gassy Sediments				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER 062435N	
6. AUTHOR(S) Mike Richardson, Warren Wood				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory Marine Geosciences Division Stennis Space Center, MS 39529-5004				8. PERFORMING ORGANIZATION REPORT NUMBER PP/7430-00-0010	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Navy Research 800 N. Quincy St. Arlington, VA 22217-5000				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release: Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT <p>Introduction Gas bubbles are ubiquitous in organic-rich, muddy sediments of coastal waters and shallow adjacent seas (Judd and Hovland, 1992; Richardson and Davis, 1998). Depths and horizontal distributions of these gas-charged sediments are usually determined from seismic profiling. The presence of gas bubbles often impedes acoustic characterization of sediments below the gas horizon and terms such as acoustic masking or blanking, acoustic turbidity, bright spots, wipeouts, and pulldowns are used to characterize these gas-charged sediments. Acoustic turbidity also produces anomalously high acoustic backscattering from the seafloor (Lyons et al., 1996; Tang, 1996) degrading the effectiveness of high-frequency sonar. Models of acoustic-bubble interactions in fine-grained sediments developed by Anderson and Hampton (1980) have been corroborated by laboratory (Gardner, 2000) and field (Wilkins and Richardson, 1998; Lyons et al., 1996; Tang, 1996; Anderson et al., 1998) experiments. In this paper, we model the effects of bubble volume, bubble size and bubble distribution on sound speed and attenuation in the well-characterized sediments of Eckernförde Bay, Baltic Sea and from experiments recently conducted in Cape Lookout Bight, North Carolina. These two areas constitute the best known and most studied area of gassy sediment in the world (Richardson and Davis, 1998; Martens et al., 1998) thus providing the ideal settings for such comparisons.</p>					
15. SUBJECT TERMS Acoustic Propagation gas bubbles, acoustic masking, blanking, turbidity, Eckernförde Bay, Cape Lookout Bight, North Carolina					
16. SECURITY CLASSIFICATION OF: Conference Proceedings Unclassified			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON MICHAEL D. RICHARDSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code) (228) 688-4621

20010907 082

ACOUSTIC PROPAGATION IN GASSY SEDIMENTS

M.D. Richardson and W.T. Wood

Marine Geosciences Division, Naval Research Laboratory
Stennis Space Center, Mississippi 39529-5004, USA
Mike.Richardson@nrlssc.navy.mil

Introduction

Gas bubbles are ubiquitous in organic-rich, muddy sediments of coastal waters and shallow adjacent seas (Judd and Hovland, 1992; Richardson and Davis, 1998). Depths and horizontal distributions of these gas-charged sediments are usually determined from seismic profiling. The presence of gas bubbles often impedes acoustic characterization of sediments below the gas horizon and terms such as acoustic masking or blanking, acoustic turbidity, bright spots, wipeouts, and pulldowns are used to characterize these gas-charged sediments. Acoustic turbidity also produces anomalously high acoustic backscattering from the seafloor (Lyons et al., 1996; Tang, 1996) degrading the effectiveness of high-frequency sonar. Models of acoustic-bubble interactions in fine-grained sediments developed by Anderson and Hampton (1980) have been corroborated by laboratory (Gardner, 2000) and field (Wilkins and Richardson, 1998; Lyons et al., 1996; Tang, 1996, Anderson et al., 1998) experiments. In this paper, we model the effects of bubble volume, bubble size and bubble distribution on sound speed and attenuation in the well-characterized sediments of Eckernförde Bay, Baltic Sea and from experiments recently conducted in Cape Lookout Bight, North Carolina. These two areas constitute the best known and most studied area of gassy sediment in the world (Richardson and Davis, 1998; Martens et al., 1998) thus providing the ideal settings for such comparisons.

Study sites: Cape Lookout Bight, North Carolina: This shallow (4-7 m water depth) coastal basin acts as a trap for organic matter exiting a back barrier island lagoon system and has the highest rates of anaerobic mineralization measured in coastal sediments (Martens and Van Klump, 1984). Methane production is highest during warm summer months with methane saturation and bubbles occurring within 10 cm bsf (below seafloor) and gas volumes as high as 12% (Martens et al., 1998). During the summer, ebullition of methane gas occurs at low tide through open cavities called "mud tubes" and methane fluxes, via ebullition, nearly equal sediment methane production rates. In the winter, methane production rates drop and

much less methane escapes the sediment. Near surface sediment gas volume is lower and methane saturation and bubbles occurs below 30 cm bsf.

Eckernförde Bay, Baltic Sea: Eckernförde Bay is the best-known and most studied gassy sediment in the world (Richardson and Davis, 1998). As early as the studies of Schüler (1952), acoustic turbidity at this site was attributed to the presence of free gas in the sediments. The uppermost acoustic horizon ranges from 50 to 200 cm bsf and migrates vertically in response to temperature, nearer the sediment-water interface when sediments are warmest (Wever and Fiedler, 1995). Rates of anaerobic mineralization are lower than at the Cape Lookout Bight site and methane concentrations vary little with season (Martens et al., 1998; Anderson et al., 1998). The bubbles resolvable by CT scan imagery range from 0.5 to 5 mm in equivalent radius with 0 - 2 % (mean 0.1 %) percent methane by volume. Higher gas volumes (up to 6%) have been reported from the numerous pockmarks. Considerable horizontal variability was found in methane bubble concentrations (by volume, number of bubbles, and size distribution) in cores collected 2-20 meters apart (Anderson et al., 1998).

Acoustic Model Predictions

Modified versions (Lyons et al., 1996; Anderson et al., 1998; Richardson and Wilkens, 1998) of the acoustic propagation models first developed by Anderson and Hampton (1980) were used to predict frequency dependent sound speed and attenuation in gassy sediments of Cape Lookout Bight and Eckernförde Bay. These models assume bubbles are large relative to particle size and that the structure of the sediment frame interacts with the bubbles and changes bubble resonance, compressibility, absorption, and scattering. The low sediment permeability, in the modeled sediments, restricts pore fluid motion and allows the use of the visco-elastic propagation models used in this paper to approximate sediment propagation predicted by more complex poro-elastic models (Stoll, 1998). Bubble size distributions in Eckernförde Bay sediments were measured using CT-scans (Anderson et al., 1998); whereas, bubble volumes for the sediments from Cape Lookout were estimated using x-radiography (Martens and Van Klump, 1980). Values of sediment and gas physical properties given by Wilkens and Richardson (1998) were used to predict sound speed and attenuation in both the gassy sediments of Eckernförde Bay and Cape Lookout Bight.

Sound speed and attenuation were first calculated assuming the entire volume of gas (0.1 to 12%) consisted of a single bubble size (Fig. 1). Most authors have used this approach because the actual distribution volumes within bubbles sizes are rarely available. Below bubble resonance (lower left quadrant of the panels in Figure 1) the sound speed ratio (ratio of sediment sound speed to sound speed of the pore water) decreases and attenuation increases with gas volume.

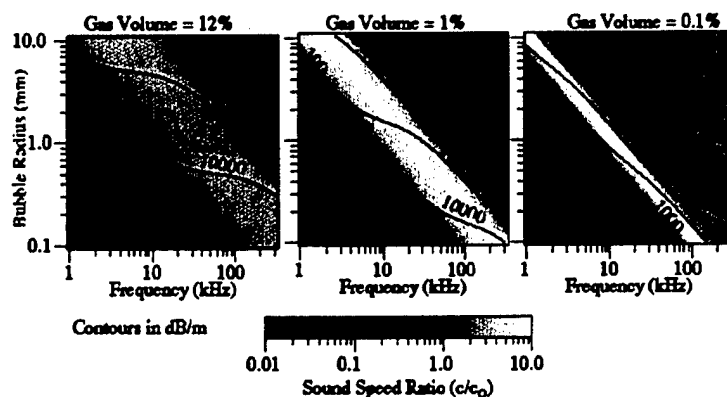


Fig. 1: Sound speed ratio (sediment sound speed divided/ pore water sound speed) and attenuation (dB m^{-1}) as a function of bubble size and acoustic frequency for bubble concentrations (12%, 1% and 0.1%) typical of Eckernförde Bay and Cape Lookout Bight.

Near bubble resonance attenuation is very high, especially at high gas volumes. Well above bubble resonance (upper right quadrants of panels in Fig. 1), sound speed is near bubble free sediments (sound speed ratio = 1) at gas volumes typical of Eckernförde Bay but much higher than gas free sediments at gas volumes typical of Cape Lookout Bight.

Sound speed and attenuation were then predicted as a function of bubble size and acoustic frequency for typical bubble concentrations found in Eckernförde Bay sediments (Fig. 2). At acoustic frequencies well above resonance (>30 kHz), bubble resonance rarely affects sound speed. Intrinsic attenuation is low and scattering from bubbles (not included in the model) probably dominates attenuation. At frequencies well below resonance (< 1 kHz) “compressibility effects” dominate, sound speed is much lower (250 m s^{-1}), and attenuation is low. Near resonance sound speed varies greatly with frequency and attenuation is very high. Analysis of in situ and remote acoustic propagation and scattering data over a frequency range of 5–400 kHz, support these model predictions (Wilkens and Richardson, 1998), especially at acoustic frequencies well above and well below the bubble resonance. Analysis of the dispersion of measured sound speeds established the upper limit of methane bubble resonance at 20–25 kHz. These data, combined with bubble sizes determined from CT scan imagery yielded estimates of effective bubble sizes between 0.3 and 8.0 mm. The lower limit of effective bubble size was smaller than the resolution of the CT-scanning technique. Values of sound speed predicted using the entire spectrum of bubble sizes (Fig. 2) were lower than predicted values based on a single bubble size (Fig. 1). These predictions are in concordance with sound speeds (1100 – 1200 m s^{-1}) reported for 5–15 kHz by Wilkens and Richardson (1998) and suggest that the proportional distribution of bubbles must be considered when predicting acoustic behavior of gassy sediment.

The bubble size spectrum provided by Martens and van Klump (1980) was used to predict sound speed and attenuation in sediments of Cape Lookout Bight (Fig 3). Note that the number of bubbles and average radii are much greater than reported for sediments in Eckernförde Bay (Fig. 2). In situ measurements of sound speed and attenuation in the upper 2-m of sediments at Cape Lookout Bight were made using wide-bandwidth transducers (5-200 kHz). These cross-hole measurements were made during winter conditions (May) and will be repeated during summer (June-October) conditions. Comparisons of recent measurements (May, 2000) and predictions presented in Fig. 3 will be presented.

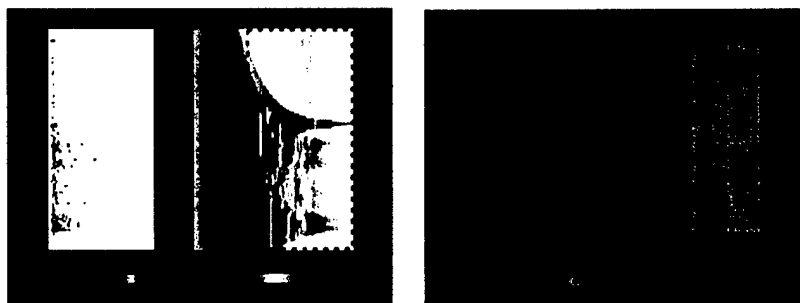


Fig. 2: Sound speed ratio and attenuation calculated for a measured bubble size distribution (site P2) typical of sediments of Eckernförde Bay (see Anderson et al., 1998) and the sediment properties given by Wilkens and Richardson (1998).



Fig. 3: Sound speed ratio and attenuation calculated for a measured bubble size distribution typical of sediments of Cape Lookout Bight (see Martens and Van Klump, 1980, 1984) and the sediment properties given by Wilkens and Richardson (1998).

Acknowledgements: The authors wish to acknowledge the important contributions of Roy Wilkens, Kevin Briggs, Fritz Abegg, Aubrey Anderson, Chris Martens and Dan Albert to this paper. We would also like to thank the captain and crew of the WFS PLANET, Ingo Stender, Thomas Wever, and their colleagues at the Forschungsanstalt

der Bundeswehr für Wissenschaft und Geophysik for their outstanding technical support and scientific collaboration during the Eckernförde Bay experiments. The Institute of Marine Sciences, University of North Carolina provided field support (R/V Capricorn) for the Cape Lookout experiments. The Office of Naval Research Program Element 0601153N supported this program.

References

- Anderson A.L. and L.D. Hampton. 1980. Acoustics of gas-bearing sediments I. Background and II. Measurements and models. *Journal of the Acoustical Society of America* (67):1865-1903.
- Anderson, A.L., F. Abegg, J.A. Hawkins, M.E. Duncan and A.P. Lyons. 1998. Bubble populations and acoustic interaction with the gassy seafloor of Eckernförde Bay. *Continental Shelf Research* (18):1807-1838.
- Gardner, T.N. 2000. An acoustic study of soils that model seabed sediments containing gas bubbles. *Journal of the Acoustical Society of America* (107):163-176.
- Judd, A.J. and M. Hovland. 1992. The evidence of shallow gas in marine sediments. *Continental Shelf Research* (12): 717-725.
- Lyons, A.P., M.E. Duncan, A.L. Anderson and J.A. Hawkins. 1996. Predictions of the acoustic scattering response of free-methane bubbles in muddy sediments. *Journal of the Acoustical Society of America* (99):163-172.
- Martens C.S., D.B. Albert and M.J. Alperin. 1998. Biochemical process controlling methane in gassy coastal sediments-Part 1. A model coupling organic matter flux to gas production, oxidation and transport. *Continental Shelf Research* (12):1741-1770.
- Martens, C.S. and J. Van Klump. 1980. Biochemical cycling in an organic-rich coastal marine basin 4. Methane sediment-water exchange processes. *Geochimica et Cosmochimica Acta* (44):471-490.
- Martens, C.S. and J. Van Klump. 1984. Biochemical cycling in an organic-rich coastal marine basin 4. An organic budget for sediments dominated by sulfate reduction and methanogenesis. *Geochimica et Cosmochimica Acta* (48):1987-2004.
- Richardson, M.D. and K.B. Briggs. 1998. In situ and laboratory geoacoustic measurements in soft mud and hard-packed sand sediments: Implications for high-frequency acoustic propagation and scattering. *Geo-Marine Letters* (16):196-203.
- Richardson, M.D. and A.M. Davis. 1998. Modeling methane-rich sediments of Eckernförde Bay. *Continental Shelf Research* (18):1671-1688.
- Schüler, F. (1952) Untersuchungen über die Mächtigkeiten von Schlickschichten mit Hilfe des Echographen, *Dt. Hydrogr. Z.*, 5, 220-231.
- Stoll, R.D. and E.O. Bautista. 1998. Using Biot theory to establish a baseline geoacoustic model for seafloor sediments. *Continental Shelf Research* (18):1839-1858.
- Tang, D. 1996. Modeling high-frequency acoustic backscattering from gas voids buried in sediments. *Geo-Marine Letters* (16):261-265.
- Wever, T.F. and H.M. Fiedler. 1995. Variability of acoustic turbidity in Eckernförde Bay (southwest Baltic Sea) related to the annual temperature cycle. *Marine Geology* (125):21-27.
- Wilkens, R.H. and M.D. Richardson. 1998. The influence of gas on sediment acoustic properties: in situ, laboratory, and theoretical results from Eckernförde Bay, Baltic Sea. *Continental Shelf Research* (18):1859-1892.